# Uncertainty monitoring in the rhesus monkey (*Macaca mulatta*)

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"Theory of mind" is in sharp focus in cognitive ethology, as researchers explore whether animals monitor and respond adaptively to others' mental states and states of knowing (Cheney & Seyfarth, 1990; Byrne & Whiten, 1991). In this paper, we urge that a separate issue not be neglected because the analytic spotlight shines so brightly *on the other*. For one might also ask if animals monitor and respond adaptively to *their own* mental states and states of knowing (Schull & Smith, 1992).

This latter question concerns animal self-awareness, another focus of primate research. Elegant comparative studies involving mirror self-recognition show that only (and not all of) the higher apes pass the mirror-dye test (Gallup & Suarez, 1986). But despite this test's value as a comparative marker, it still needs a sharper cognitive theory behind it (for what do animals recognize in the mirror - self, mind, only body?). In this paper, we urge that theories of animal self-awareness be refined through the development of additional paradigms which assay additional facets of self-awareness. For example, mirror self-recognition need not imply that animals recognize or monitor their own cognitive processes - therefore, we targeted just this *cognitive* self-awareness. And this led us to ask if primates monitor objective or subjective signals of uncertainty about a problem, or if in some sense they "know when they don't know."

### Information-seeking by animals

Animals, faced with laboratory problems, do detect situations in which they have inadequate information. For example, dolphins echolocate more intently and monkeys gaze longer when trying to identify difficult stimuli (Schrier & Wing, 1973; Roitblat et al., 1990). Animals will even acquire arbitrary operants which provide access to informative stimuli (Dinsmoor, 1983), and make these "observing responses" more frequently when information is most needed (D'Amato et al., 1968).

Such findings may suggest that animals monitor their problem-solving activities, and seek additional cues when they feel uncertain or confused, as humans have been shown to do (Baker, 1985; Acredolo & O'Connor, 1991). However, information-seeking could also be occasioned by objective, external stimuli. For example, D'Amato et al. found that monkeys sought more information for underlearned stimuli and for stimuli whose significance had recently changed. But these information-seeking responses could have been prompted by a local increase in errors or by the problematic (and aversive) discriminative stimuli themselves.

Clearly, it is difficult to engender a state of psychological uncertainty without also providing clear stimulus cues, and this is the key problem facing the animal "uncertainty" researcher. Our approach is to minimize the salience of external, objective uncertainty cues, and force animals to self-regulate by monitoring internal states of uncertainty, if they have the capacity to do so. If present, this capacity would be quite interesting, because it might represent a primitive form of metacognitive self-regulation and even an introspective capacity in parallel to the extrospective capacity which most animal-mind researchers seek.

*The uncertainty paradigm*

Our procedure resembles many psychophysical paradigms that measure perceptual thresholds and sensitivities by bringing animals to the limits of their discrimination abilities (e.g., Nachtigall, 1986), and it also recalls early behavioral experiments which used impossibly fine discriminations to induce animal "psychosis" (e.g., Anderson & Parmenter, 1941). Our crucial departure from those procedures is to offer animals an escape response which can be used at some cost to escape into an easier trial (Weissman et al., 1984). Given its cost, animals should only use this response sparingly, when errors are likely. But in order to do this, they need to identify the occasions when they are not able to reliably solve the primary discrimination. In this paper, we report that monkeys do use the escape response in exactly this way, we discuss the cues and states which might occasion these escape responses, and we consider the possibility that escapes from difficult discrimination trials may represent an adaptive response to a psychological state of uncertainty.

**Method**

Two 9-yr-old male rhesus monkeys *(Macaca mulatta)* were tested unrestrained, at free-feeding weight, in their home cages. Water was always available, and each animal received his full daily food ration through rewards and supplementary feeding. Animals were tested using the

Language Research Center's Computerized Test System (LRC-CTS; Washburn & Rumbaugh, 1992) in which a PC/XT-compatible computer generates visual stimuli, to which subjects respond using a standard analog joystick. Both animals had previously learned to use a joystick to move a cursor in a variety of computer tasks (Washburn et al., 1991). Correct responses earned food pellets and audio feedback. Incorrect responses earned a long timeout period with auditory feedback.

On each trial the animal moved the cursor to one of three objects on the screen - a Box, an "S", or a Star (Fig. 1a). The critical stimulus dimension was the number of illuminated pixels in the Box. With 2950 pixels, the trial was termed "Dense," and touching the Box was the correct response; with *any number fewer*, the trial was "Sparse," and the S was correct. At first, only easily discriminable Dense and Sparse stimuli were presented (2950 pixels vs. 450 pixels), and only the Box and S appeared on the screen. With this basic discrimination established, more difficult S-correct stimuli (e.g., 2750 pixels) were introduced on 33% of trials. The difficulty of these probe stimuli could be increased in 100 negatively accelerating steps from 450 illuminated pixels to 2949 pixels, but for trials at all these levels the S-response was still correct. The program automatically tracked the subject's last 10 probe trials and increased the difficulty of the stimuli when performance was above 50%, and decreased difficulty when performance fell below 50%. Thus, the difficulty of these probe trials was titrated against performance to maintain chance discrimination on them.

As probe trials were first made difficult, the Star was introduced. Touching the Star cleared the screen and initiated a guaranteed-win trial, containing *only* a Box or an S. Animals were taught the Star's function through occasional trials in which the cursor would only go down to the Star. But the animal had to transfer the use of the Star from these "Forced" trials to difficult discrimination trials. Overuse of the Star increasingly delayed the arrival of the guaranteed-win trial, so it was best used sparingly. Because incorrect responses earned a timeout, but overuse of the Star reduced its utility, the animal's optimal strategy was to try the primary discrimination whenever possible, and escape only the most difficult probe trials.

### Results

The monkeys acquired the basic density discrimination in about 4 hours of testing. Both monkeys immediately transferred the use of the Star from Forced trials to difficult probe trials, and they began using the Star systematically almost as soon as the probe trials became too difficult to solve reliably. After monkeys were fully trained, they completed over 40,000 trials in the mature experiment, and only these trials were analyzed.

Figures 1b and 1c show the results from monkeys Abel and Baker, respectively. On the sparser trials, S responses predominated, whereas Box responses predominated on Dense trials and the most difficult probe trials. Where these two response curves cross, the discrimination was performed at
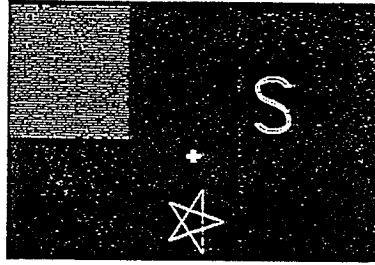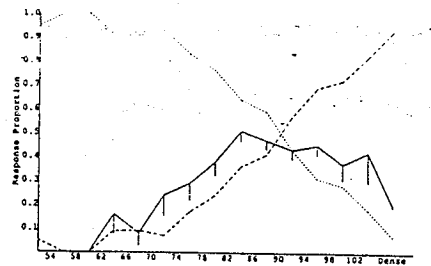
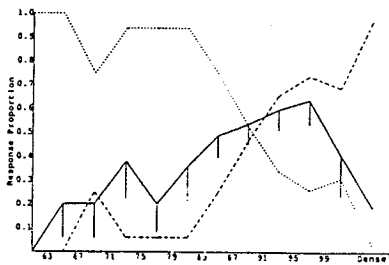a. The screen from a "Dense" trial in the task used with monkeys and humans
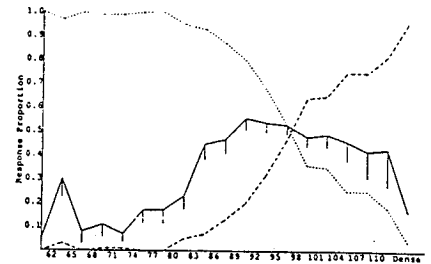
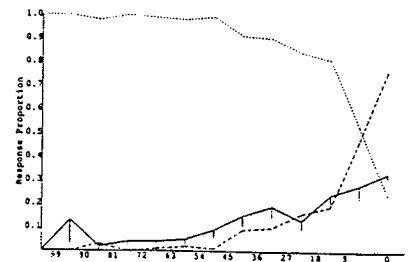b. Performance by monkey Abel (low-cost escapes)
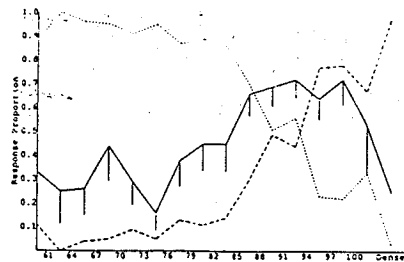
c. Performance by monkey Baker (low-cost escapes)

d. Performance by 15 human adults

e. Performance by monkey Baker (high-cost escapes)

f. Performance by rat Newton

**Fig. 1.** In panels b-f, the horizontal axis indicates the difficulty of the probe trial, which could be increased in 100 steps. The solid line represents the proportion of trials at a particular difficulty level on which the subject made the bailout response. The error bars show the lower 95% confidence limits. The proportion of remaining trials ending with each primary response are indicated by the dashed and dotted lines.

chance, and it was in this region of maximum uncertainty that animals were most likely to use the Star. Thus, monkeys correctly assessed when they were at risk for error, and escaped adaptively in that circumstance.

The monkeys' performance was essentially identical to that of humans (Fig. 1d), and we asked human subjects when they chose each target. For the Box and the S, they referred to *objective stimulus conditions* (the density of dots in the Box). For the Star, they always referred to *subjective mental states* - "When I wasn't sure" or "When I couldn't tell." Thus, Star responses in humans are different from the two primary discrimination responses, and may be comments or confidence judgments about the primary discrimination. Given identical data from monkeys, one wonders how similar monkeys' escape responses are to humans' (uncertainty-based) escape responses. Do monkeys also know when they don't know? To answer this question, one must identify the cues or processes which occasion escape responses. As with any other assay of "mind" in animals, one proceeds cautiously, accepting high-level psychological cues only after rejecting possible low-level stimulus-based cues. In our case, several obvious low-level accounts of escape behaviors clearly fail.

*Escape behaviors: ruling out some possible objective cues*

First, perhaps the monkeys hesitated or vacillated on difficult probe trials, allowing long latencies or circuitous cursor movements to become objective cues for escape responses. However, such behaviors were followed by all three possible responses, not selectively by Star responses, and these hesitation behaviors were essentially eliminated in animals' mature performance. Second, perhaps animals escaped from stimuli associated with low rates of reward. This account fails because reinforcement histories are quite asymmetrical about the discrimination crossover (animals are usually wrong for right-of-crossover stimuli) whereas under normal circumstances the escape curves are relatively symmetrical. Third, perhaps animals escaped whenever errors suddenly increased. This cue has often been available in research on information-seeking, as, for example, when a discrimination is reversed and errors suddenly increase. But our procedure offered the animals a total steady state, with frequent errors for both Probe Trials and Denses, and within that constancy animals had to decide on each trial what to do. Fourth, perhaps animals escaped when they perceived the distinctive features for a third objective stimulus class, intermediate between Denses and Sparses. However, this strategy would have quickly extinguished, because animals would have used those same features to make the S response, and win, on all these trials.

Furthermore, animals cannot even distinguish Denses from Sparses at th crossover, so there is no psychophysical room for a third discriminabl stimulus class between.

The failure of these low-level interpretations indirectly strengthens a: explanation in terms of something like uncertainty monitoring.

*Escape behaviors: carving the perceptual continuum into*
*three comparable regions*

Even so, there are more subtle "middle stimulus" accounts, which suppose that the animal divides the whole continuum of sensory impression into three regions, using two psychological criteria or cutpoints, and thei responds Sparse to impressions below the lower criterion, Dense t( impressions above the upper criterion, and Star to impressions in the middl( region. This description predicts essentially the escape curves we obtain. W( discuss this class of explanations in detail elsewhere (Smith et al., ms.), so w( will make just three points here.

First, this description leaves unspecified the psychology of the animal': criterion points. In humans, the criteria overlain on sensory continua are ofte1 defined by uncertainty and confidence, are often conscious, explicit, an( verbalizable, and in any case are clearly second-order judgments about th( primary discrimination. In all respects, they are meta- to the discrimination. I the criteria used by the monkeys are similar, then escape responses are a valic behavioral inventory of the animal's *judgment about* the perceptua information.

Second, most middle-region hypotheses predict that escape behavior; will peak just at the discrimination crossover because this crossover defines the middle of the middle region. Yet, monkeys show a right-shifted peak o: escape behaviors under some circumstances, that is, when the Star is made expensive (Fig. 1e). This phenomenon undermines any straightforward middle-region hypothesis, but it is consistent with the idea that monkeys, faced with an expensive Star, strategically reserve its use for trials right of crossover which are usually lost (Smith et al., ms.).

Third, middle-region hypotheses framed in terms of conflict, general-ization gradients, response strengths, or displacement activities all predict that the laboratory rat, who demonstrates all these gradient phenomena, should also be able to escape adaptively from crossover trials. Yet, we find that rats consistently fail to escape crossover trials within our paradigm. Figure 1f shows the performance of a superior animal, Newton, who discriminated well,

and was able to use the escape response when difficult trials were signaled by *objective stimulus cues.* For example, he avoided objective stimuli towards the right end of the stimulus continuum, where many of his difficulties lay. Newton's only deficit was that he failed to detect any signal of uncertainty, or of potential error, at the discrimination's crossover. He was blind to some escape cue which monkeys sense very easily, and which humans call uncertainty. Newton's failure suggests that our procedure does minimize objective escape cues, because he would have found them, and used them, if they had been clearly present. These results constrain one's sense of the kinds of signals monkeys monitor in order to escape. And as low-level interpretations of the phenomenon falter, a natural and parsimonious interpretation remains: perhaps monkeys' escape behaviors are close cognitive analogues of humans' uncertainty-based escape behaviors.

### Discussion

We believe our data reveal a primitive kind of *self-monitoring* by monkeys, in which they monitor some more subjective signal of uncertainty to make adaptive escape responses. Seen in that light, our research extends prior research which demonstrates that animals can monitor their own recent behaviors and use them as discriminative stimuli (Beninger et al., 1974).

However, we have not shown that monkeys *consciously* "know" when they do not know, nor that they have any explicit awareness of themselves as actors within the task (Crook, 1983). It may be that monkeys' uncertainty monitoring is more *procedural* than *declarative.* Nevertheless, we find it interesting that, whereas humans explained their primary discrimination responses using *objective stimulus terms,* they explained their escape responses using *personal terms,* e.g., "When *I* wasn't sure." Thus, in humans at least, *cognitive* self-awareness is somehow linked to *personal* self-awareness.

Our uncertainty paradigm is applicable to any species amenable to psychophysical testing. It thus provides a broad comparative technique, available for identifying the conditions allowing uncertainty processes in different species. One hypothesis, that inner speech is an essential substrate for cognitive monitoring (Vygotsky, 1978) is infirmed by our results. Another hypothesis is that complex social interactions promote self-awareness (Humphrey, 1976) - if so, then social species would more clearly show cognitive self-awareness, or perhaps only highly encephalized mammals will show successful uncertainty monitoring - suggestively, rats fail, while

monkeys and humans succeed, in our task. We are currently studying oth
primate species, since a primate failure in our task (a solitary primate, a low
primate) would now be as interesting a result as another primate success.

But our broader purpose is to promote the development and comparativ
study of new self-awareness paradigms, for this will directly benefit the theoi
of mind literature (Griffin, 1976). First, new techniques will highlight neglecte
areas of research. For example, the study of theories of mind could incluc
animals' capacities to know and monitor their own minds, too, though thes
capacities have gone essentially unexplored. Second, new techniques can poir
out hidden assumptions in the literature. For example, it is often assume
that awareness of the others' mental states, and awareness of one's ow
mental states are tightly linked functionally or phylogenetically (cf. Cheney i
Seyfarth, 1990). But this assumption is not empirically supported. Moreove:
the other- and self-knowing capacities could be subject to differen
evolutionary pressures, could be subserved by different cognitive mechanisms
and could have quite different distributions across species (Schull & Smith
1992). Third, new techniques may reveal informative mosaics of success an
failure by primates. For example, though monkeys fail to self-recognize ii
mirrors, and fail to read the other's state of knowing, they apparently do sens
when they themselves do not know. Such mixed results from divers
paradigms should encourage us, and practitioners of other techniques, t
undertake a closer analysis of the cognitive processes and representation:
which underlie the different performances we study. As cognitive scientists, wi
believe that this more psychological focus will be a valuable next step fo
studying animals' theories of mind - both their own and that of the other.

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### References

Acredolo, C. & O'Connor, J. (1991). On the difficulty of detecting cognitive uncertainty. Hum.
  Develop. 34: 204-223.
Anderson, O.D. & Parmenter, R. (1941). A long-term study of the experimental neurosis in the
  sheep and dog. Psychosom. Med. Monogr. 2, 3 & 4: 1-150.
Baker, L. (1985). How do we know when we don't understand? Standards for evaluating text
  comprehension. In Forrest-Pressley, D.L., MacKinnon, G.E. & Waller, T.G. (eds.), Meta-
  cognition, cognition, and human performance. Academic Press, New York, pp. 155-205.
Beninger, R.J., Kendall, B. & Vanderwolf, C.H. (1974). The ability of rats to discriminate their
  own behavior. Can. J. Psychol. 28: 79-91.

Byrne, R.W. & Whiten, A. (1991). Computation and mindreading in primate tactical deception. In Whiten, A. (ed.), *Natural theories of mind: Evolution, development and simulation of every-day mindreading*, Basil Blackwell, Oxford, pp. 127-141.

Cheney, D.L. & Seyfarth, R.M. (1990). *How monkeys see the world*. University of Chicago Press, Chicago.

Crook, J.H. (1983). On attributing consciousness to animals. *Nature* 303: 11-14.

D'Amato, M.R., Etkin, M. & Fazzaro, J. (1968). Cue-producing behavior in the capuchin during reversal, extinction, acquisition, and overtraining. *J. Exp. Anal. Behav.* 11: 425-433.

Dinsmoor, J.A. (1983). Observing and conditioned reinforcement. *Behav. Brain Sci.* 6: 693-728.

Gallup, G.G., & Suarez, S.D. (1986). Self-awareness and the emergence of mind in humans and other primates. In Suls, J. & Greenwald, A. (eds.), *Psychological perspectives on the self, Vol. 3*, Erlbaum, Hillsdale, NJ, pp. 3-26.

Griffin, D.R. (1976). *The question of animal awareness: Evolutionary continuity of mental experience*. Rockefeller University Press, New York.

Humphrey, N.K. (1976). The social function of the intellect. In Bateson, P.P.G. & Hinde, R.A. (eds.), *Growing points in ethology*, Cambridge University Press, Cambridge, pp. 303-317.

Nachtigall, P.E. (1986). Vision, audition, and chemoreception in dolphins and other marine mammals. In Schusterman, R.J., Thomas, J.A. & Wood, F.G. (eds.), *Dolphin cognition and behavior: A comparative approach*, Erlbaum, Hillsdale, NJ, pp. 79-114.

Roitblat, H.L., Penner, R.H. & Nachtigall, P.E. (1990). Matching-to-sample by an echolocating dolphin (*Tursiops truncatus*). *J. Exp. Psychol. Anim. Behav. Proc.* 16: 85-95.

Schrier, A.M. & Wing, T.G. (1973). Eye movements of monkeys during brightness discrimination and discrimination reversal. *Anim. Learn. Behav.* 1: 145-150.

Schull, J. & Smith, J.D. (1992). Knowing thyself, knowing the other: They're not the same. *Behav. Brain Sci.* 15: 166-167.

Smith, J.D., Schull, J., Washburn, D.A. & Shield, W.E. (ms.). The "uncertain" response in humans and animals.

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes*. Cole, M. (ed.), Harvard University Press, Cambridge, MA.

Washburn, D. A. & Rumbaugh, D. M. (1992). Testing primates with joystick-based automated apparatus: Lessons from the Language Research Center's Computerized Test System. *Behav. Res. Meth. Instrum. Comput.* 24: 157-164.

Washburn, D.A., Hopkins, W.D. & Rumbaugh, D.M. (1991). Perceived control in rhesus monkeys (*Macaca mulatta*): Enhanced video-task performance. *J. Exp. Psychol. Anim. Behav. Proc.* 17: 123-129.

Weissman, R., Gibson, M. & Rochford, J. (1984). Testing models of delayed sequence discrimination in pigeons: The advance key procedure. *Can. J. Psychol.* 38: 256-268.

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